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SENSITIVITY ANALYSIS OF SPECTRAL PROPERTIES USING MULTISENSOR IMAGE DATA*

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Knowledge about the spectral variability in a field or region of interest becomes important when it comes to defining a representative spectrum of a certain spatial extent, used for example as an endmember in spectral unmixing techniques. An approach is presented using high spatial resolution panchromatic data to assess the spectral variability of a hyperspectral dataset. The spatial variability is combined with spectral variability using spatial statistics such as auto correlation and correlation length applied to the co-registered database of the two sources. Data fusion methods and analysis applied in this manner can help to support the interpretation of high resolution spectral and spatial data in order to support future applications such as precision farming.

1.0 INTRODUCTION

In August 1997 the Digital Airborne Imaging Spectrometer (DAIS 7915) and the Wide Angle Airborne Camera (WAAC), both operated by DLR (German Aerospace Research Establishment) have been flown simultaneously over an intensively cultivated agricultural area, the Limpach Valley, in Western Switzerland (470 m a.s.l.). The valley consists mainly of crops, meadows and sugar beet. The area covered by the DAIS is 2.5 km by 10 km whereas the WAAC has a swath width of slightly more than 5 km from the reported flight altitude of 3840 m a.s.l.

A major problem in the quantitative analysis of hyperspectral datasets is the reliable selection of reference spectra for the classification of heterogeneously vegetated areas or for retrieval of biogeophysical parameters from these reference spectra. Three methods of collecting endmember spectra for spectral unmixing were presented, discussed and verified in previous work [1]. These methods include spectroradiometric measurements of reference targets in the field, modelling endmember spectra using a SVAT (soil-vegetation-atmosphere-transfer) approach as well as image based selection of endmember spectra. Such reference spectra are selected within the inner part of a field under the assumption of its spectral and spatial homogeneity.

It could be demonstrated that a persistent problem in spectral unmixing is the underrepresentation of endmember spectra obtained from field measurements, derived from the image or obtained by applying a SVAT-approach. This leads usually to larger errors or even negative abundances of the unmixing results.

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In this paper, an approach for integrating high spatial resolution panchromatic scanner data as a secondary data source into hyperspectral data to assess spatial variability of within field inhomogeneities is presented. The use of high spatial resolution panchromatic data in addition to high spectral resolution imaging spectrometer data yields the potential of supporting spectral unmixing analysis.

2.0 EXPERIMENT DESCRIPTION

In August 1997, the DAIS imaging spectrometer [2] and the wide angle airborne camera WAAC [3] were simultaneously flown aboard DLR's Dornier DO228 aircraft. For the WAAC camera, no stabilized platform was used. In addition to the INS in the nose of the DO228, a gyro block was mounted directly on the camera base plate. The DAIS sensor is mounted on shock mounts to prevent the scanner from aircraft vibrations, which introduces additional degrees of freedom for airplane attitude data. The different behavior of the two sensors relative to the airplane becomes important when co-registering the two datasets.

Numerous spectroradiometric measurements on selected reference targets have been taken in the test area using a GER-3700 spectroradiometer. This 704 channel spectroradiometer covers the 400-2500 nm wavelength range. Mapping of the land cover and determination of the field borders is based on areal photography. This helps to identify more than 90 fields with their landcover both in the DAIS and WAAC datasets.

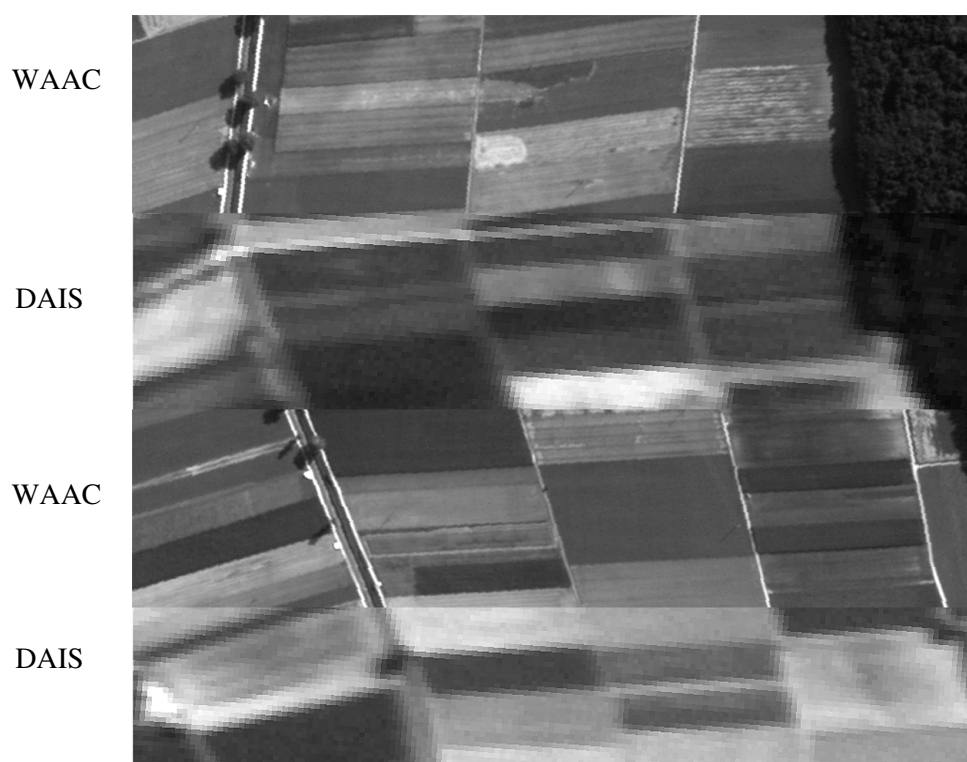


Figure 1. Co-registered high spatial resolution data (WAAC) and high spectral resolution data (DAIS, channel 9).

2.1. DAIS SYSTEM DESCRIPTION

The DAIS 7915 is a 79-channel high resolution optical spectrometer that covers the wavelength range between 500 nm and 12000 nm using a Kennedy type scanning mechanism. The first 72 channels cover the reflective part of the electromagnetic spectrum whereas the channels 73-79 cover the MIR and TIR range. The DAIS has a swath angle of 52° , subdivided into 512 pixels per scanline. The IFOV used is 3.3 mrad, resulting in a ground instantaneous field of view of 11m from the reported flight altitude of 3840m a.s.l. and a ground sampling distance of 5.5 m because of an approximately three times oversampling during the datatake.

2.2. WAAC SYSTEM DESCRIPTION

WAAC is a miniaturized Wide-Angle Optoelectronic Stereo Scanner (WAOSS) that was developed for the Russian Mars-96 mission. The Wide Angle Airborne Camera WAAC is a three line stereo pushbroom scanner. The IFOV of WAAC is 0.32 mrad, 10 times smaller than the IFOV of DAIS. The geometrical resolution of WAAC is about 1.2 m from the reported flight altitude of 3840 m a.s.l. The nadir line covers the wavelength range between 450 nm and 700 nm and the backward/forward line the range from 600 nm to 800 nm. The FOV of WAAC is 80° with 5184 elements per CCD line.

3.0 DATA PROCESSING

3.1. WAAC

The WAAC data is radiometrically corrected by DLR. It is attitude corrected and geocorrected onto a flat plain of mean height above sea level. Especially in the Limpach Valley this process offers good positional accuracy, since the valley, as the main region of interest, is an absolutely flat area with a mean height of 470 m a.s.l.

3.2. DAIS

The DAIS 7915 data are provided as radiance calibrated data from DLR. The preprocessing of the imaging spectrometer data includes MNF (Minimum Noise Fraction) transformation to reduce noise. The atmospheric correction is performed using ATCOR-2 [4], an atmospheric correction program, based on lookup tables generated with a radiative transfer code (MODTRAN-3), to convert the data to apparent reflectances.

The DAIS data used in this study were co-registered to the WAAC scene by using ground control points and a second order polynomial function. By doing so, a further resampling of the geocorrected (but not yet geocoded) WAAC dataset, which was chosen as geometric reference, could be avoided. However, to get highest spatial accuracy, both the WAAC and DAIS data should be geocoded and assigned a reference system using a parametric geocoding approach (PARGE [5]) including a digital elevation model and the attitude data of the aircraft. Figure 2 shows the process proposed for datafusion of the two datasets.

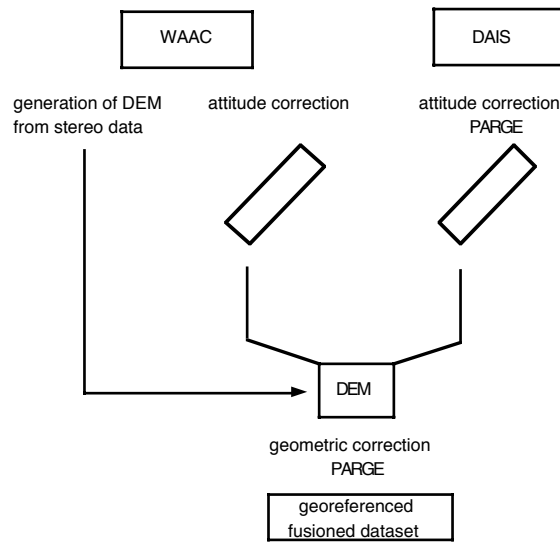


Figure 2. Process of georeferencing proposed for fusion of high spatial and high spectral resolution image data.

By co-registering the DAIS data onto the WAAC data, the DAIS pixels were resampled to the 1m resolution of the WAAC. A procedure was developed to determine the centerpixel of the oversampled DAIS scene, to assign clusters of 5 by 5 WAAC pixels to the DAIS data. An oversampled DAIS pixel (1m by 1m) is considered as centerpoint if, for the four main directions, each value at a distance of two pixels is equal to the centerpoint value. As a second constraint, neighboring centerpoints must not lie closer than five pixels from each other to preserve the original dimensions of the DAIS pixels (5 m by 5 m).

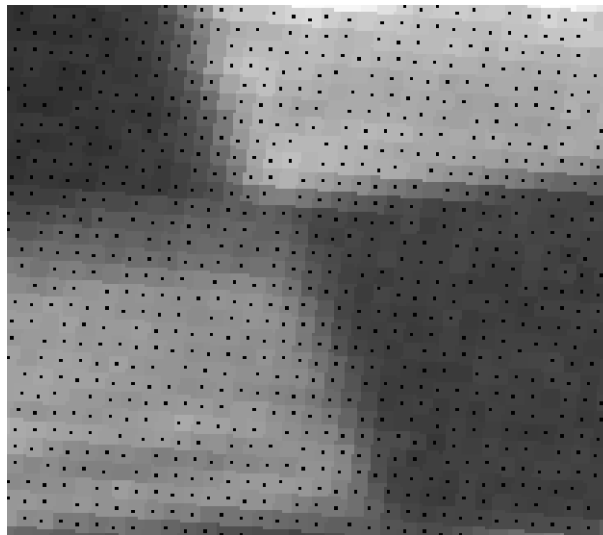


Figure 3. Subpart of the oversampled DAIS scene. The DAIS data (5 m by 5 m) were oversampled to fit the dimensions of WAAC (1m by 1m). Each dot illustrates a DAIS pixel centerpoints that corresponds to a 5 m by 5 m WAAC cluster.

The co-registration process for the two data sources (DAIS and WAAC) is of great importance to assess spectral and spatial changes within a region of interest.

4.0 METHODOLOGY

The high spatial resolution panchromatic channel of WAAC is sensitive between 450 nm and 700 nm for the nadir line, which is used in this study. This wavelength range is covered by the DAIS with the channels 1 to 12, ranging from 501nm to 689 nm. Only these 12 channels will be used here.

Each channel of the DAIS sensor is correlated to the corresponding digital numbers (DN's) of WAAC using linear regression. Figure 4 and Figure 5 show a strong linear relationship between DAIS reflectance values for each channel and DN values of WAAC for a region of interest (wheat).

As a basic assumption, the spectral variation in each DAIS channel is considered as linearly related to the DN variation of WAAC. Figure 6 shows the mean reflectance ρ_{mean} for a defined region of interest, as well as $\rho_{\text{mean}} \pm 1\delta(\rho_{\text{mean}})$ and $\rho_{\text{mean}} \pm 2\delta(\rho_{\text{mean}})$.

Since the interval $[\rho_{\text{mean}} - 2\delta(\rho_{\text{mean}}), \rho_{\text{mean}} + 2\delta(\rho_{\text{mean}})]$ consists of 95% of all data of a normally distributed dataset, the spectral variation of this interval can be set into relation to the variation of DN's in the WAAC scene for each channel.

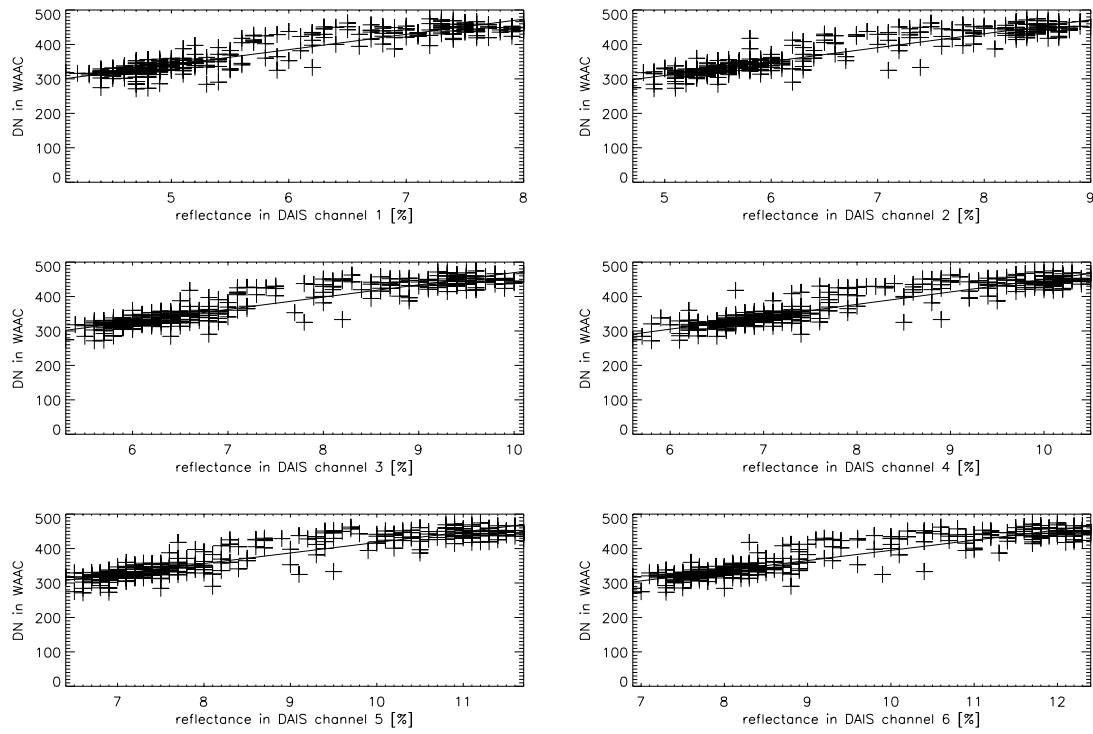


Figure 4. Linear regression between reflectances of DAIS for channels 1 to 6 and DN's of the WAAC.

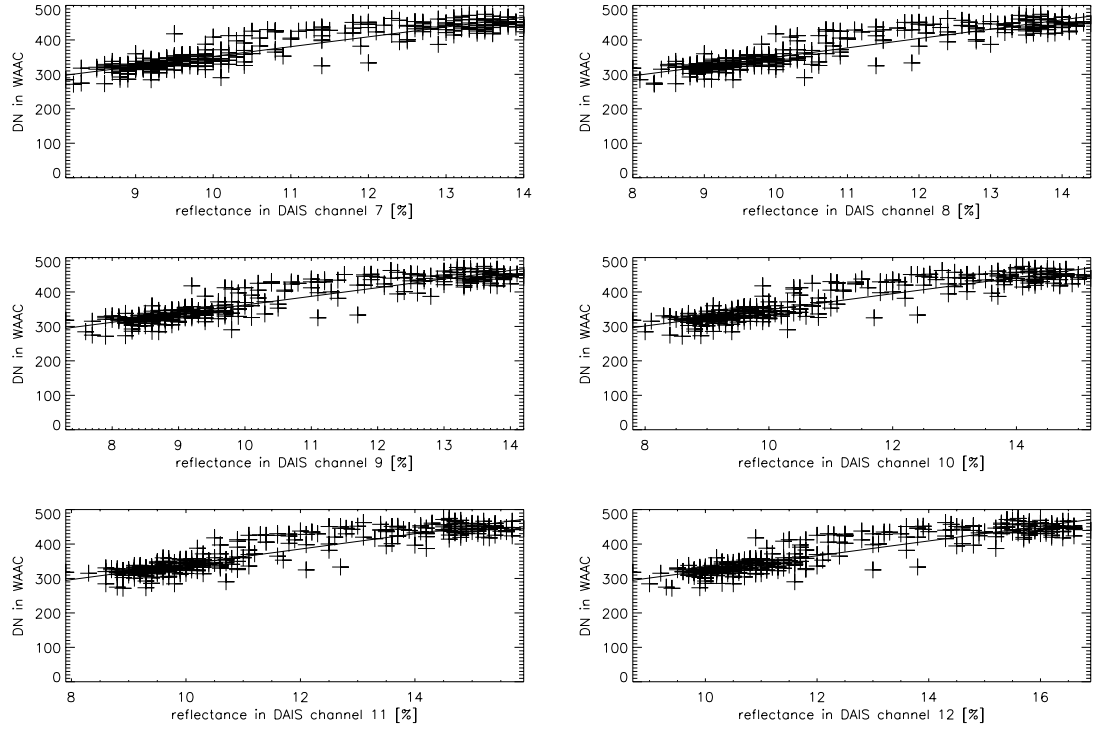


Figure 5. Linear regression between reflectances of DAIS for channels 7 to 12 and DN's of the WAAC.

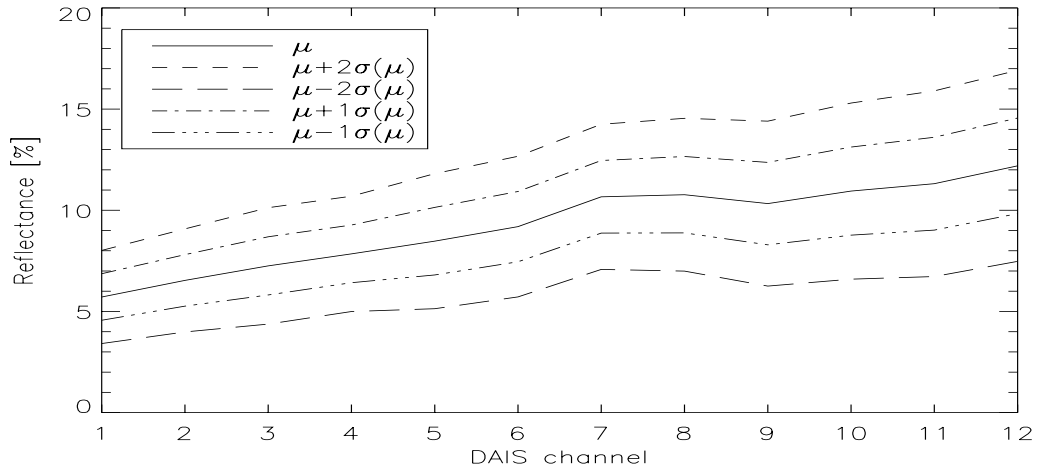


Figure 6. Spectral variability of a harvested wheat field characterized by ρ_{mean} , $\rho_{\text{mean}} \pm 1\delta(\rho_{\text{mean}})$ and $\rho_{\text{mean}} \pm 2\delta(\rho_{\text{mean}})$ for the DAIS channels 1 to 12.

The WAAC camera, bearing the potential of high spatial resolution, offers the possibility of assessing spatial variability within regions of interests such as single fields in agricultural areas. Spatial statistics, such as auto correlation, can link the spectral variabilities to spatial variations. Spatial auto correlation is a measure of covariance between observations divided by the variance of the data. The correlation length may be defined as the corresponding lag at which the auto correlation function (or covariance function) falls to a specified level, typically $\exp(-1)$ of its value for zero lag [6]. The auto correlation formulation requires stationarity, i.e. the mean is assumed to remain constant over the entire extent of the variable [7]. The success of auto correlation and correlation length analysis depends on the optimal choice of regions of interest. Generally speaking, a region of interest for which auto correlation is a meaningful descriptor should be ‘homogeneous’, or in terms of statistical signal analysis ‘stationary’. Too small data arrays and regions of interest with different mean levels, separated by sharp edges, can cause problems.

The auto correlation function (ACF) used in this study is computed via FFT. To find the maximal correlation length in the data the ridge in the auto correlation function along which its decay is slowest is determined. Then, a least-squares polynomial fit to the ACF cross-section along this ridge is computed and the point where the polynomial fit falls to a specified level, typically $\exp(-1)$, is defined as the maximal correlation length. The minimal correlation length is defined by the ACF cross-section along the direction orthogonal to the ACF ridge of slowest decay.

The mean difference of DN values for WAAC is determined for a region of interest both for maximal and minimal correlation lengths. Assuming a linear relationship between WAAC DN’s and DAIS reflectances, as illustrated in Figure 4 and Figure 5, the maximal change of reflectance within a given correlation length can be calculated. As a result, reflectance values of two spectra can be considered as auto correlated if their difference in reflectance does not exceed a certain value defined by the correlation length and the corresponding range of DN values from WAAC.

5.0 CONCLUSIONS

The approach presented is evaluated and discussed for two selected regions of interest, a harvested wheat field, of which the spectrum is plotted in Figure 6, and a field of corn. Both fields show strong linear structures, especially the wheat field. Therefore, the maximal and minimal correlation lengths are expected to differ significantly. Figure 7 shows the auto correlation functions for the two regions of interest.

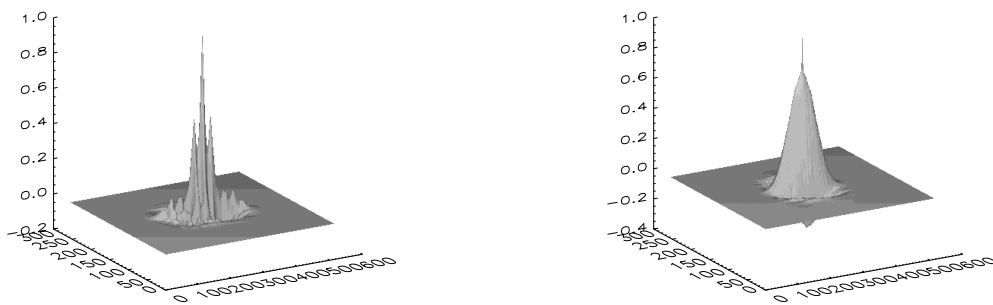


Figure 7. Auto correlation functions of two regions of interest: harvested wheat field (left), corn field (right). Especially the auto correlation function for wheat reflects the predominant influence of single rows.

The maximal correlation length as calculated for wheat is 31 pixels, the minimal correlation length 6 pixels. These values strongly reflect the linear shape of the field's rows. The mean difference of DN values of WAAC for both lengths is $\Delta DN=25.75$.

The corn dataset has a maximal correlation length of 44 pixels and a minimal correlation length of 9 pixels. Since the corn field is more homogeneous than the wheat field, its mean difference of WAAC DN values is only $\Delta DN=5.7$.

Relating these ΔDN 's to reflectance changes of each DAIS channel shows that reflectance differences of less than 10% between two spectra result in the fact that the two spectra, under the assumptions made in this study, do not correlate significantly anymore. While the correlation length allows reflectance changes of around 4% to 5% for DAIS channel 1 to 3, DAIS channels 4 to 12 allow reflectance changes between 6% and 10% before such spectra are no longer auto correlated on the specified level exp(-1).

It remains to be evaluated if the combined use of correlation length and related mean spectral changes is a powerful approach of characterizing spectral variability within a region of interest since reflectance changes of up to 10% between two measurements of the same object are not unusual, especially in agricultural studies. Nevertheless, the use of first and second order statistics in high resolution spatial data offers the possibility of assessing spatial variation within fields which becomes important in precision farming.

Both high spatial resolution data and high spectral resolution data contain specific information, be it geometrical and positional on the one hand or spectral information on the other hand. Fusion of such two datasets produces subpixel information content. The use of multisensor image data offers the possibility of determining the spectrally purest pixel in a field, used for example by spectral unmixing. Investigation of the variance within well defined clusters of pixels of the high resolution spatial data could help finding the cluster of lowest variance (window size of 5 pixels for WAAC, corresponding to the original resolution of DAIS). The corresponding spectrum of this cluster, being the most homogeneous, could represent the region of interest in an unmixing analysis.

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